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Results From the Dutch Speech-in-Noise Screening Test by Telephone

Cas Smits and Tammo Houtgast

Objective: **The objective of the study was to implement a previously developed automatic speech-in-noise screening test by telephone (Smits, Kapteyn, & Houtgast, 2004), introduce it nationwide as a self-test, and analyze the results.**

Design: **The test was implemented on an interactive voice response system, which can handle multiple lines. The test measures the speech reception threshold in speech-shaped noise by telephone ($SRTT_n$) in an adaptive procedure using digit triplets as speech material. The test result is given as either good, insufficient, or poor. Questions about age, sex, and subjective rating of hearing were included in the test. The test was introduced as the National Hearing test and publicity was generated. In the first 4 mo, 65,924 people took the initiative and dialed the test. The possibility to use mobile phones was disabled because of significant worse results (0.7 dB) with that telephone type.**

Results: **After applying exclusion criteria, results from 39,968 callers were analyzed. Seventy-five percent of the callers were older than 44 yr of age. Starting at about 45 yr of age, there is an increase in $SRTT_n$ with increasing age. $SRTT_n$s for men are significantly worse than $SRTT_n$s for women for age groups 50 to 54 and higher. Older people tend to rate their hearing better than might be expected from their $SRTT_n$. However, after converting the mean $SRTT_n$ values per age group and per subjective score to percentile values, the values remain constant across age groups. Mean measurement error was within 1 dB. These errors increase with increasing $SRTT_n$.**

Conclusions: **This study shows the implementation and results from a functional hearing screening test by telephone. The test can be done in about 3 minutes, 30 sec, including introductory text, explanation of the test procedure, test result, and recommendation for audiological evaluation. The high number of callers implies that the test is probably fulfilling the need for a functional hearing screening test and has enhanced public awareness about hearing loss.**

(Ear & Hearing 2005;26;89–95)

Hearing disability is strongly age-related and is one of the most common health problems of older people. It is known that adults tend to ignore the effects of hearing loss and delay their decision to seek audiological help for their problems. Prevalence of hearing aid use is relatively low in older age groups (Popelka, Cruickshanks, Wiley, Tweed, Klein, & Klein, 1998). There exist many simple self-administered questionnaires on hearing disability. They usually consist of 10 to 12 items, but research data on validity, reliability, and so forth is rare. The American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) developed a questionnaire called the Five-Minute Hearing test. Koike et al. (1994) found 97% sensitivity and 5% specificity for this test, which means that almost everyone is referred irrespective of the amount of hearing loss. Other self-administered questionnaires (Schow & Nerbonne, 1982; Ventry & Weinstein, 1983) are often used but primarily in scientific research or by screening practitioners and not as self-tests. Pure-tone hearing screening by telephone is also available in some countries but is characterized by numerous limitations and the lack of published research data (ASHA, 1988). Therefore, there is a real need for a reliable, convenient, quick, and low-cost self-test for hearing disability.

In a previous paper, Smits et al. (2004) described the development and validation of an automatic speech-in-noise test by telephone. The hearing test was developed to meet the need for a functional self-test and to enhance the public awareness of hearing loss. It is expected that an easy accessible hearing test might incite people with hearing disability to seek medical help.

The test measures the Speech Reception Threshold in noise by telephone using digit triplets as speech material ($SRTT_n$). The $SRTT_n$ represents the signal-to-noise ratio, where a person recognizes 50% of the speech material correctly. It was decided to measure the ability for understanding speech in noise for two reasons. First, disability in understanding speech in noise is the most frequent disability among hearing-impaired people (Kramer, Kapteyn, & Festen, 1998). Second, the $SRTT_n$ is insensitive for absolute presentation level at higher levels and, therefore, speech-in-noise tests can be performed reliably by telephone. It is important to note that the test measures hearing disability and not hearing impairment. The correlation between

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the new test and the existing sentence SRT_n test by headphones of Plomp and Mimpen (1979) was found to be 0.87, whereas a correlation between $PTA_{0.5,\ 1,\ 2,\ 4}$ and $SRTT_n$ of 0.77 was found (Smits et al., 2004). A limitation of using speech-in-noise measurements as a screening tool is that it is not sensitive for detecting pure conductive hearing losses. The ability for speech understanding in noise is strongly deteriorated by sensorineural hearing losses and, in addition, subjects with central auditory processing disorders often have problems with understanding speech in noise. However, the ability for understanding speech in noise is not much deteriorated by pure conductive hearing losses.

The test measures the $SRTT_n$ by using an adaptive procedure (simple up-down method): The signal-to-noise ratio of the next presentation increases by 2 dB after an incorrect response and decreases by 2 dB after a correct response. The subject responds using the telephone keys. A response is judged to be correct only when all three digits are correct. A series of 23 triplets is chosen randomly out of 80 triplets for one $SRTT_n$ measurement: The $SRTT_n$ is calculated by averaging the signal-to-noise ratios of the last 20 presentation levels (the last presentation level is based on the last response). No significant influence of telephone type or listening environment was found. Measurement errors were within 1 dB and are comparable to the sentence SRT_n test by headphones performed in a clinical setting. Further details can be found in Smits et al. (2004).

This article describes the implementation of the test by which it became possible to do the test with many people at the same time. Questions about sex, age, and rating of hearing ability were included in the test. It was decided to use numerical self-rating of hearing ability, which resembles the procedure of Lutman and Robinson (1992) and Corthals et al. (1997). A limitation of using a simple single question is that people rate their hearing from their general auditory experience. This will not necessarily be their ability to understand speech in noise. However, as mentioned before, disability in understanding speech in noise is the most frequent disability among hearing-impaired people (Kramer et al., 1998).

In cooperation with the Dutch Hearing Foundation (Nationale Hoorstichting), publicity was generated, which resulted in a high number of calls. Detailed results from the first 4 mo are presented in this article.

METHODS

Implementation on an Interactive Voice Response System • The setup as described in Smits et al. (2004) uses a computer with modem and modem software to mix noise and speech, play the triplets, judge the response, and calculate the $SRTT_n$. With that setup, it was not possible to do multiple measurements simultaneously. To be able to perform measurements simultaneously, it is necessary to have multiple lines and to have hardware and software to handle the calls. Therefore, it was chosen to implement the test on an interactive voice response system at a telephone company. Real-time mixing and adjusting levels became impossible, and sound files for every triplet at different signal-to-noise ratios were made. The range of signal-to-noise ratios was limited to −12 dB and +8 dB, because this range should be wide enough to perform adaptive $SRTT_n$ measurements for most normal-hearing and hearing-impaired people. With a step size of 2 dB and 80 different triplets, this resulted in 880 sound files. When the response to a triplet presented at +8 dB is incorrect, the next triplet is presented again at +8 dB, and when a correct response is given to a triplet at −12 dB, the next triplet is presented again at −12 dB. Starting level of the $SRTT_n$ test (signal-to-noise ratio of the first triplet) was set to 0 dB, which makes the first triplet easy to understand for normal-hearing and most hearing-impaired subjects. From every call, detailed information was stored, including all presented and responded triplets.

Test Procedure • To get some information about the people who did the test, a few questions preceded the actual speech-in-noise test. When the call is put through, first the cost of the test per minute is given (€0.35), then a welcome message is played and the callers are asked whether they want to receive information from the Dutch Hearing Foundation. Then, they are asked to enter their age, sex, and to rate their hearing with a number between 1 (very poor hearing) and 9 (excellent hearing). After this, the test procedure is explained and the test starts.

Test Results • As shown in Smits et al. (2004), the test has a sensitivity and specificity of 0.91 and 0.93, respectively, for distinguishing normal-hearing from hearing-impaired subjects. To increase the differentiation, an extra category for the hearing-impaired was introduced. Limits were based on the sentences SRT_n test by headphones (Plomp & Mimpen, 1979), the standard speech-in-noise test in the Netherlands that uses sentences in stationary speech-shaped noise. Limits for these test were chosen at SRT_ns −3.0 and 0.0 dB, corresponding to $SRTT_n$s of −4.1 and −1.4 dB, respectively (using equation 2 in Smits et al., 2004). After the test, the test result, including recommendation for audiological evaluation, is played and can be repeated by the caller. Results were given as:

Good ($SRTT_n < -4.1$ dB): "The outcome of the test is good. This test measures just a single aspect of hearing. It may happen that you still doubt your hearing, despite the outcome of this test. In such a case you could, for example, suffer from a conductive hearing loss. When in doubt, you can visit a hearing aid dispenser or make an appointment with your GP, ENT doctor, or Audiological Center."

Insufficient ($-4.1 \text{ dB} \leq SRTT_n \leq -1.4$ dB): "Your hearing is insufficient. You might already have been aware of that. It is advisable to have your hearing more thoroughly tested. You can visit a hearing aid dispenser or make an appointment with your GP, ENT doctor, or Audiological Center."

Poor ($SRTT_n > -1.4$ dB): "Your hearing is poor. We strongly advise you to make an appointment with your GP, ENT doctor, Audiological Center, or hearing aid dispenser for more thorough tests of your hearing."

RESULTS

Results from January 1 to April 30 were analyzed; 65,924 people dialed the number and were connected. On several days, e.g., when national television paid attention to the test, the number of lines (45) was insufficient to handle all the calls. From the people who got connected, 2% could not send DMTF tones, required for the response, and 12% hung up during introductory text or the questions, 86% started with the test (speech-in-noise measurement), and 84% finished the test completely.

For further analysis of the $SRTT_n$ data, a few exclusion criteria were applied: a maximum of three times no response (more than 99% of the $SRTT_n$ measurements) was allowed and measurements that contained an incorrect response at a signal-to-noise ratio of +8 dB were excluded (2%). The latter measurements will give incorrect $SRTT_n$ values because the maximum signal-to-noise ratio was limited to +8 dB. However, the test result will be correct in most cases (poor hearing is the most likely test result).

As will be shown in the next paragraph the use of mobile (cellular) phones gave significantly worse results. Therefore, the possibility to do the test by a mobile phone was ended in the beginning of March. Tests done by mobile phones and by unknown telephone type were excluded from the final analysis. This resulted in 39,968 $SRTT_n$ measurements.

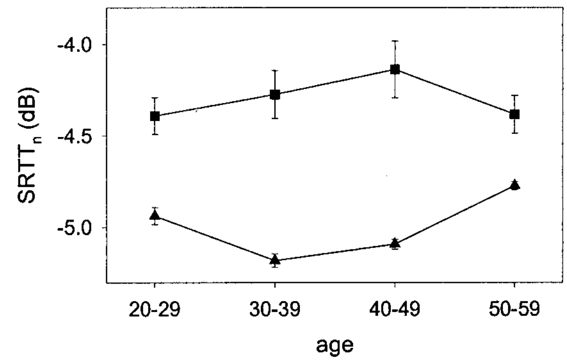

Fig. 1. Mean speech reception threshold in speech-shaped noise by telephone ($SRTT_n$) and standard error versus age for different telephone types. ■, data from mobile phones; ▲, data from conventional phone. Differences between $SRTT_n$s for mobile phones and conventional phones are significant ($p < 0.001$) for every age group.

Mobile Phones

It was hypothesized that the use of mobile phones would give less reliable results, because sound quality and listening environment was expected to be worse compared with the use of conventional phones. Therefore, for the month of January, additional information about used telephone type was acquired from the telephone company. This information was derived from the telephone number. Number of calls from conventional phone, mobile phone, and unknown telephone type were 32,587, 998, and 4767, respectively. Figure 1 shows the mean $SRTT_n$ versus age group for mobile phones and conventional phones. Only age groups with at least 100 $SRTT_n$s per telephone type are shown. Over these age groups, the average difference between the mean $SRTT_n$ by mobile phone and by conventional phone equals 0.70 dB. For every age group the difference was significant ($p < 0.001$; t-test). The mean $SRTT_n$ by unknown telephone type (not shown) lies, as expected, between the mean $SRTT_n$ by mobile phone and by conventional phone. As mentioned before, because of the significant difference the test setup was adjusted to make the use of mobile phones impossible.

$SRTT_n$ and Test Result Versus Age and Sex

In Figure 2, a histogram and a cumulative histogram show the occurrence of different $SRTT_n$ values. Boundaries depicting different test results are also given. It can be seen that the test results good, insufficient, and poor were given to about 67%, 26%, and 6% of the callers, respectively. Figure 3 shows the age distribution of the callers. There is a clear maximum between about 50 to 70 yr. Seventy-five percent of the callers were older than 44 yr of age. Median age was 56 and 54 yr for men and women, respectively.

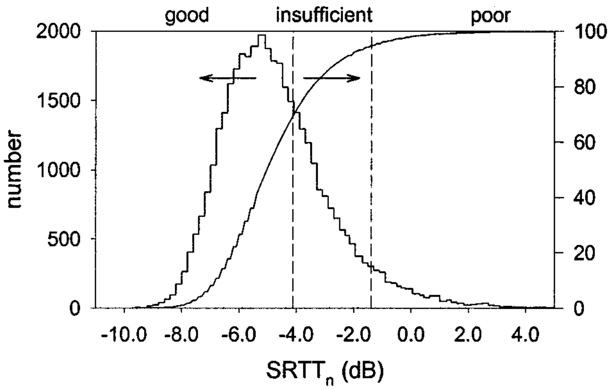

Fig. 2. Histogram and cumulative histogram of SRTT$_n$s in 0.2-dB intervals. Vertical dotted lines depict borders between the different test results in terms of good, insufficient, and poor.

It is also of interest to examine the relationship between SRTT$_n$ and age. Results for men and women were separately pooled in 5-yr-wide age groups and are presented in Figure 4. Only age groups with at least 50 SRTT$_n$s per sex are shown. To detect significant differences between male and female scores, for every age group, results were compared. Because the distributions are skewed positively (especially for the older age groups) the Mann-Whitney U test was used and revealed significant differences between male and female scores for age group 50 to 54 ($p < 0.05$) and for the five age groups between 55 and 80 yr ($p < 0.005$).

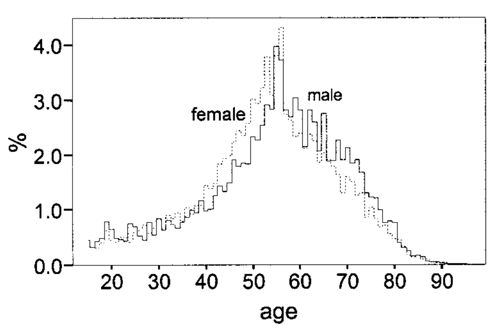

Fig. 3. Percentage of callers versus age for men and women. Solid line represents men; dashed line represents women.

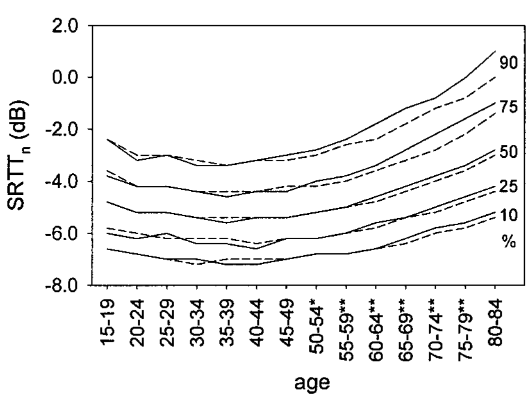

Fig. 4. SRTT$_n$ versus age for men (solid lines) and women (dashed lines). Median and percentiles 10, 25, 75, and 90 are given. Age groups with significant differences between men and women are marked by *($p < 0.05$) and **($p < 0.005$).

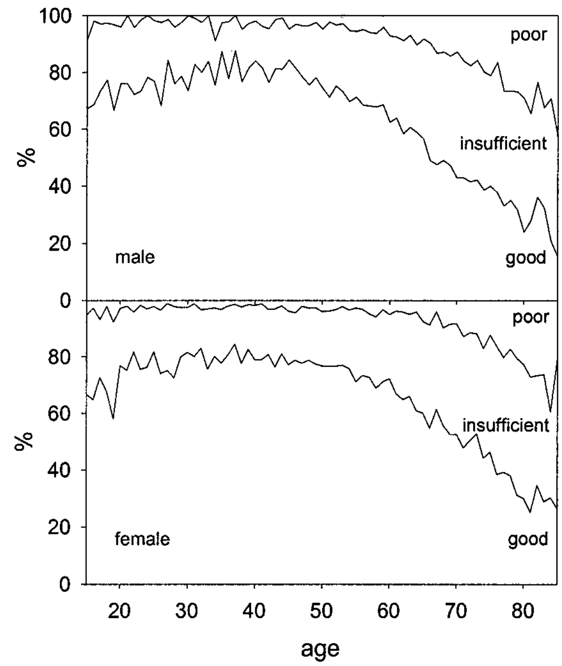

Fig. 5. Occurrence of different test results versus age for men (upper panel) and women (lower panel).

As expected, SRTT$_n$s increase with increasing age, however, the 35 to 39 yr age group seems to get better SRTT$_n$ scores than the younger age groups. This finding was unexpected because best SRTT$_n$s were expected in the 20 to 24 yr age group. Therefore, SRTT$_n$s from callers between 20 and 40 yr (four age groups) were further explored. For men and women separately, testing of homogeneity of variance (Levene test) revealed no differences in variance between the four age groups ($p = 0.98$ and $p = 0.64$ for men and women, respectively), which suggests that the worse SRTT$_n$s for the lower age groups is not due to a different distribution (more hearing-impaired callers compared with normal-hearing callers would result in a broader distribution). Linear least-squares regression on mean SRTT$_n$ versus age yielded regression lines with significant ($p < 0.01$) negative slopes: −0.022 dB/yr and −0.017 dB/yr for men and women, respectively. Apparently, the SRTT$_n$s improves with age in the 20 to 40 yr age range, but obviously, these results are clinically not relevant.

Because the test result consists of three categories, age effects become more prominent in a plot of test result versus age (Fig. 5). The percentage of

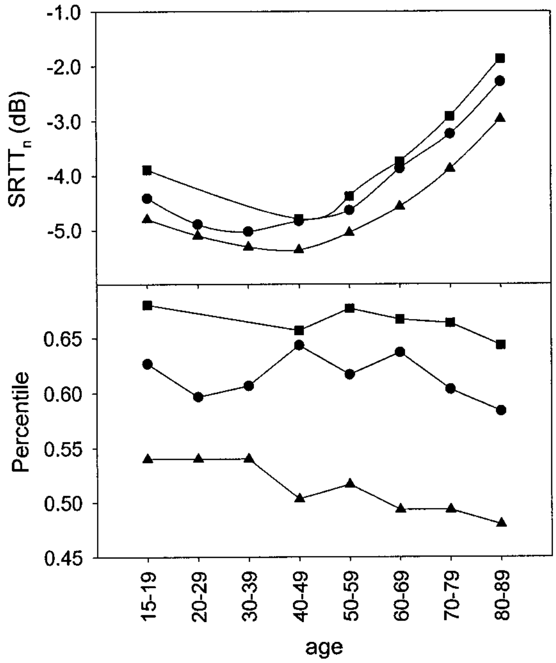

Fig. 6. Upper panel shows mean SRTT$_n$ versus age group. Data for callers with subjective rating 7–8–9 (▲), 4–5–6 (●), and 1–2–3 (■) are shown. Lower panel shows the percentile score for the different data points within the age group. Only data points based on at least 100 SRTT$_n$s are shown.

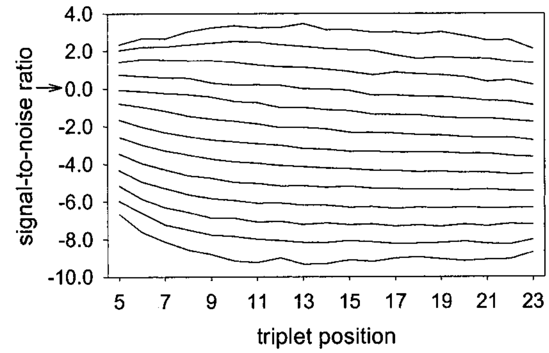

Fig. 7. Mean signal-to-noise ratio for the different positions in the adaptive procedure. Results are shown for different SRTT$_n$ groups: Upper line represents SRTT$_n$ = 3 dB, lower line represents SRTT$_n$ = −9 dB. Arrow at 0 dB indicates the starting level.

callers with test result good decreases from about 80% in the 30 to 34 and 35 to 39 yr age groups to about 30% in the 80 to 84 yr age group.

SRTT$_n$ and Test Result Versus Subjective Rating

People who dialed the test were asked to rate their hearing (1 = very poor, 9 = excellent). Although the spread is very high, SRTT$_n$s decrease with increasing subjective rating. In the upper panel of Figure 6, the relations between mean SRTT$_n$ and age for different subjective ratings are shown. Scores are averaged for subjective rating 1–2–3, 4–5–6, and 7–8–9. It is clear that age is a more prominent factor than subjective rating and older people tend to rate their hearing better than might be expected from their SRTT$_n$. One reason for this finding could be that most elderly people have social contacts with people in their age group and therefore relate their hearing to them. The lower panel of Figure 6 shows the same relations as the upper panel, but instead of mean SRTT$_n$ the percentile score for the SRTT$_n$ value in that age group is shown. Now, subjective rating is much more important than age. Using regression models to predict the percentile scores in the lower panel of Figure 6 from subjective rating scores and age shows that 88% of the variance can be explained by subjective rating alone. The explained variance increases to 92% by including age. The figure indicates that subjective rating of hearing ability is correlated to individual disability in understanding speech in noise relative to that age group.

Reliability of the Test

It is well known that most speech-in-noise tests show a learning effect: Results improve during testing. Besides this, the test result could be influenced by the fact that starting level is identical for everyone and, therefore, the difficulty of the first presentation depends on amount of hearing loss. In the test the first four presentations are omitted for both reasons. Figure 7 shows the mean signal-to-noise ratio for the different positions in the adaptive procedure. Results are shown for 1-dB SRTT$_n$s groups. Only data points representing means from at least 50 signal-to-noise ratios are shown. Both effects mentioned above can be seen. The steep slope up to position 8 for the lowest SRTT$_n$ values probably is due to the starting level at 0 dB. For all but the best and worse SRTT$_n$ values, a learning effect can be seen by the steady decline in mean SNR value.

Additional analyses can be done by splitting up every single SRTT$_n$ measurement (Smits et al., 2004). The first and last 10 presentations used for the calculation of the SRTT$_n$ are considered as separate measurements. The learning effect, represented by the mean difference between both SRTT$_n$s, equals 0.73 dB, with only small differences between the SRTT$_n$ groups.

The reliability of the test using 10 presentations can be calculated from the standard deviation of the differences between both SRTT$_n$s, divided by $\sqrt{2}$. It should be noted that the learning effect is outbal-

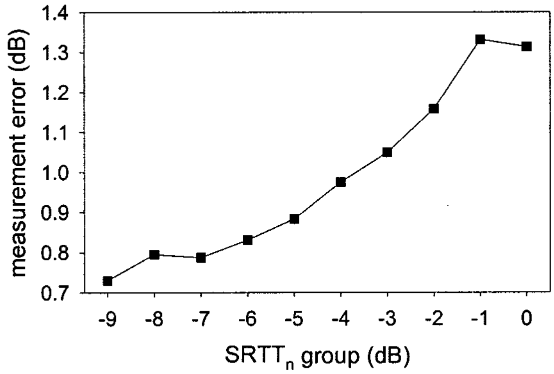

Fig. 8. Measurement error versus SRTT$_n$. Accuracy of the test decreases with increasing hearing loss. SRTT$_n$ groups above 0 dB are omitted because the exclusion of SRTT$_n$ measurements in which there was a wrong response at +8 dB signal-to-noise ratio has a significant effect for these data points.

anced with this procedure.* The reliability of the test (measurement error), when using all 20 presentations, can be estimated by dividing the result by $\sqrt{2}$. When taking all measurements together, this value equals 0.95 dB. Figure 8 shows the estimated measurement error for different SRTT$_n$ groups. There is a clear increase in measurement error with increasing SRTT$_n$: Values go from about 0.8 dB for SRTT$_n$ groups −8 and −7 dB to about 1.3 dB for SRTT$_n$ groups −1 and 0 dB.

DISCUSSION

Demographic data shows that the test is for the greater part done by people over 50 yr of age. It cannot be ruled out that the media campaign has reached a selective public. However, probably the main reason is that presbyacusis results in problems with understanding speech in noise for these age groups. The reason that the distribution of SRTT$_n$s in Figure 2 is rather small, probably stems from the fact that only few people with moderate or severe hearing loss did the test because they already know that they have a significant hearing loss, and many of them even have trouble using the telephone. Figures 4 and 5 show the increase in hearing disability for these age groups. It is important to note that both figures are, very likely, not based on an unbiased group. Therefore, these data cannot be compared directly with published data.

The upper panel of Figure 6 clearly shows the inadequacy in using simple numerical self-rating of hearing ability to predict the ability for understanding speech in noise, especially by the older age groups. This result is in line with the result of Wiley et al. (2000). They noted that after adjusting for the degree of hearing loss, the probability of reporting a hearing handicap decreases with age. They used the hearing handicap inventory for the elderly-screening version (HHIE-S) for assessing self-reported hearing handicap and compared the scores with average pure-tone thresholds. A difficulty in comparing subjective data to psychophysical data can arise from the fact that measures of hearing handicap are compared with measures of hearing impairment or, as in the study presented here, a general self-reported measure of hearing disability is compared with a specific disability measure. Wiley et al. (2000) gave some arguments to explain the observed age trend. The lower panel of Figure 6 suggests that subjects relate their score to their age group when rating their hearing abilities, which might be a reason, too, for the finding that older adults overestimate their hearing abilities. It has several implications. First, the use of a single question to assess hearing disability for screening purposes is inadequate and will result in a fairly low sensitivity for older age groups. This is in agreement with the results of Nondahl et al. (1998), who found, for the age group 65 to 92 yr, sensitivity of 67% and 43% for the single question "Do you feel you have a hearing loss?" and the question "In general, would you say your hearing is: excellent, very good, good, fair, poor?" respectively. For the HHIE-S, they even found worse sensitivity (32%). A second implication is that elder people belief that their hearing is still good, even when hearing deteriorates with age. This could be one reason for the fact that hearing aid use is relatively low in older populations.

The reliability of the test, derived from the standard deviation of differences between SRTT$_n$s, is less than 1 dB averaged over all measurements. Important to note is that callers only received a short explanation of the test (prerecorded message played through the telephone). Figure 8 shows an increase in measurement error with increasing SRTT$_n$. For the group with SRTT$_n$ = −7 dB, exactly the same value, 0.8 dB, is found as in the developing phase (Smits et al. 2004). At that time, subjects participated in a scientific research project and received extensive information about the test procedure. Therefore, the explanation in this test appears to be sufficient. Different reasons could result in an increase in measurement error with increasing SRTT$_n$. The homogeneity of the speech material can be distorted for subjects with hearing loss. Also, it is likely that some people have responded unexpected/

*Used formula

$$\sqrt{\frac{\sum(difference - \overline{difference})^2}{n}} / \sqrt{2}$$

Plomp and Mimpen (1979) *used the same formula with the mean difference omitted.*

randomly to see how it changes the test result or they did not understand the test. In these cases, both $SRTT_n$ and measurement errors will increase. Although an increase in measurement error is unwanted, for screening purposes it is most important to have a small measurement error for $SRTT_n$ values around −4.1 dB (i.e., limit of the test result "good"). Here, the measurement error is still within 1 dB.

This study shows the implementation and results from a functional hearing screening test by telephone. The test can be done in about 3 minutes, 30 sec, including introductory text, explanation of the test procedure, test result, and recommendation for audiological evaluation. It should be noted that this test is not intended for measuring pure-tone thresholds (hearing impairment) but for measuring the ability for understanding speech in noise (hearing disability). In the first 4 mo, 65,924 people did the test, which implies that the test is probably fulfilling the need for a functional hearing screening test and has enhanced public awareness about hearing loss.

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